Position Sensor with Resistive Element

BACKGROUND

The present invention relates to position sensing.

A position sensor may be used to detect the linear displacement and/or angular rotation of moving objects and components in a variety of applications. For example, a position sensor may be provided to detect the movement of a human or a human body part. In one application, sensed human movement may be used to make diagnostic and/or anatomical determinations, such as by being used to study a human's range of motion or a human's kinesthetic activities. In another application, the movements of the human may be used to control the operation of a device or process. For example, a position sensor may be used in a computer interface device to detect a user's manipulation of the device. The detected manipulation may then be used to provide input to a computer system to control computer-generated objects and environments, to control physical objects, and/or to instruct the computer to perform tasks. In one application, a user interacts with a computer-generated environment, such as a game, a surgical simulation, a graphical user interface, or other environment generated in response to an application program, by manipulating an object such as a mouse, joystick, trackball, gamepad, rotary knob, three dimensionally translatable object, or the like, to control a graphical image, such as a cursor, within a graphical environment or to otherwise control the operation of the computer. In another application, the sensed motion of a master device may be used to control the movement and positioning of a slave device.

Conventional position sensors often either have relatively low resolution or are relatively expensive to manufacture. For example, a conventional analog potentiometer is inexpensive, but often has a linearity that varies by over 5%. Thus, the potentiometer offers poor accuracy when used for large ranges of motion detection without detailed calibration. Optical encoders, which operate by alternately allowing and preventing an emitted beam to be detected by a detector, have resolutions limited by the spacing of encoder divisions. The higher the resolution, the more closely spaced the encoder divisions must be. However, as the encoder division spacing is reduced below about 2 mm, the costs associated with the encoder wheel or bar, the illumination, the detectors, and the alignment features increases above that which is acceptable for mass production of low cost products. To gain a higher sensing resolution and to

allow for the direction of movement to the determined, quadrature is often provided by using two detectors, which are 90 degrees out of phase with one another. This allows one detector to sense a threshold amount of light before the other detector when the slotted member is moved and causes the other detector to provide a detection signal out of phase with the first detector, thereby increasing the resolution since additional position detections are made, and allowing for the determination of the direction of movement by comparing the detected signals. Even higher resolution can be provided by interpolation between the slots. However, high resolution encoders are often too costly to implement in low-cost, high-volume consumer products. Alternatively, magnetic encoders, which count magnetic domains of opposite polarity, and electrical encoders, which count alternating strips of conductive and insulating material, may be used instead of the optical encoder, but these also have the resolution and costs issues of the optical encoder.

Thus, it is desirable to provide a position sensor which may be manufactured for a relatively low cost and/or which has a relatively high resolution. It is further desirable to provide a position sensor that may be used to improve the performance and/or lower the cost of a computer interface device.

SUMMARY

The present invention satisfies these needs. In one aspect of the invention, a position sensor comprises a resistive element positionable on a first surface; a pair of leads on the resistive element, the pair of leads adapted to supply a first voltage; an intermediate lead on the resistive element between the pair of leads, the intermediate lead adapted to provide a second voltage; and a contact element positionable on a second surface, the contact element adapted to contact at least a portion of the resistive element to detect a voltage at a contact position, the detected voltage being related to the position or movement of the second surface relative to the first surface.

In another aspect of the invention, a position sensor comprises a resistive element positionable on a first surface, the resistive element comprising first and second resistive strips; a plurality of leads on each resistive strip to provide a voltage to each resistive strip; and a contact element positionable on a second surface, the contact element adapted to contact at least

a portion of the resistive element to detect a voltage at a contact position, the detected voltage being related to the position or movement of the second surface relative to the first surface.

In another aspect of the invention, a position sensor comprises a resistive element positionable on a first surface, the resistive element comprising a plurality of portions; a plurality of leads adapted to provide a voltage to the resistive element; a contact element positionable on a second surface, the contact element adapted to contact the resistive element to detect a voltage at a contact position, the detected voltage being related to the position or movement of the second surface relative to the first surface; and a voltage controller adapted to selectively provide a voltage to the portions of the resistive element in relation to the position of the contact element relative to the resistive element.

In another aspect of the invention, a position sensor comprises a resistive element positionable on a first surface; a pair of leads on the resistive element, the pair of leads adapted to supply a first voltage; a contact element positionable on a second surface, the contact element adapted to contact at least a portion of the resistive element and to provide a second voltage to the resistive element; and an intermediate lead on the resistive element between the pair of leads, the intermediate lead adapted to detect a voltage, the detected voltage being related to the position or movement of the second surface relative to the first surface.

In another aspect of the invention, an interface device is provided for interfacing a user with a computer, the computer running an application program and generating a graphical image and a graphical object. The interface device comprises a user manipulatable object in communication with the computer; and a sensor comprising a resistive element on a first surface and a contact element on a second surface, the resistive element comprising a plurality of leads adapted to provide a first voltage and a plurality of leads adapted to provide a second voltage, whereby the contact element contacts at least a portion of the resistive element to detect a voltage at a contact position, the detected voltage being related to the manipulation of the user manipulatable object and usable to control the graphical object.

DRAWINGS

These features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims, and accompanying drawings which illustrate exemplary features of the invention. However, it is to be understood that each of the features can be used in the invention in general, not merely in the context of the particular drawings, and the invention includes any combination of these features, where:

1 Figure 1 is a schematic perspective view of a position sensor comprising a resistive element according to the present invention;

Figure 2 is a schematic sectional side view of a version of a position sensor comprising a resistive element having a plurality of electrical leads;

Figure 2a is a graph showing a voltage profile for the position sensor of Figure 2;

Figure 3 is a schematic side view of a resistive element having a plurality of grounded leads and a plurality of intermediate leads;

Figure 3a is a graph showing a voltage profile for a position sensor using the resistive element of Figure 3;

2 Figure 4 is a schematic sectional side view of a position sensor having a resistive element comprising a plurality of resistive strips;

Figure 4a is a graph showing a voltage profile for the position sensor of Figure 4;

3 Figure 5 is a schematic perspective view of a position sensor having a plurality of resistive elements;

Figure 6 is a schematic view of a portion of a position sensor having a plurality of resistive elements;

Figure 6a is a graph showing a voltage profile for the position sensor of Figure 6;

Figure 7 is a schematic view of a portion of another version of a position sensor having a plurality of resistive elements;

Figure 7a is a graph showing a voltage profile for the position sensor of Figure 7.

Figure 8 is a schematic view of a portion of another version of a position sensor having a plurality of resistive elements;

Figure 8a is a graph showing a voltage profile for the position sensor of Figure 8;

Figure 9 is a schematic view of a portion of another version of a position sensor having a plurality of resistive elements;

Figure 9a is a graph showing a voltage profile for the position sensor of Figure 9;

Figure 10 is a schematic view of a portion of another version of a position sensor having a plurality of resistive elements;

Figure 10a is a graph showing a voltage profile for the position sensor of Figure 10;

Figure 11 is a schematic view of a portion of another version of a position sensor having a plurality of resistive elements;

Figure 12 is a schematic view of a portion of another version of a position sensor having a plurality of resistive elements;

Figure 12a is a graph showing a voltage profile for the position sensor of Figure 12;

Figure 13 is a schematic perspective view of a position sensor having a plurality of contact brushes;

Figure 14 is a schematic view of a position sensor having a plurality of contact brushes;

Figure 14a is a graph showing a voltage profile for the position sensor of Figure 14;

Figure 15 is a schematic view of another version of a position sensor having a plurality of contact brushes;

Figure 15a is a graph showing a voltage profile for the position sensor of Figure 15;

Figure 16 is a schematic view of a rotary position sensor;

Figure 17 is a schematic view of another version of a rotary position sensor;

Figure 18 is a graph showing a voltage profile for the position sensor of Figure 16 and the position sensor of Figure 17;

Figure 19 is a schematic view of another version of a rotary position sensor;

Figure 20 is a schematic view of another version of a rotary position sensor;

Figure 21 is a graph showing a voltage profile for the position sensor of Figure 19 and the position sensor of Figure 20;

Figure 22 is a schematic view of a user interactive system having an interface device with a position sensor according to the present invention;

Figure 23 is a schematic view of a system having a goniometer having a position sensor;

Figure 24 is a schematic sectional side view of another version of a position sensor; and

Figure 25 is a schematic view of a version of a position sensor having a voltage controller.

DESCRIPTION

The present invention relates to position sensing, such as the detection of linear position or angular rotation of an object relative to another object. Although illustrated at least partly in the context of user interface devices, the present invention can be used in other applications and should not be limited to the examples provided herein.

Figure 1 is a schematic view of a position sensor **100** according to the present invention. The position sensor **100** is capable of detecting a relative or absolute position of a first surface **105** with respect to a second surface **110**. In the version shown in Figure 1, the first surface **105** is linearly displaceable relative to the second surface **110**. A resistive element **120** comprises resistive material **121** which may be in the form of one or more resistive strips positioned on or in the first surface **105**. By resistive strip it is meant a substantially continuous area of resistive material **121**. The resistive material **121** may comprise, for example, one or more of resistive ink, metallic oxide, metallic oxide with glass, cermet, metal foil, metal wire windings, conductive plastic, and the like, and may have an electrical resistance of from about 5 Ohms to about 10 MOhms, more preferably from about 100 Ohms to about 1 MOhm, and most preferably from about 10 kOhms to about 50 kOhms. In the version shown in Figure 1, a voltage source **130** supplies a voltage to the resistive element **120** so that the voltage varies along the length of the resistive element **120**. A contact element **135** is positioned on or in the second surface **110** to contact, or otherwise electrically engage, the resistive element **120**. For example, the contact element **135** may comprise one or more brushes **140,** or the like, comprising conductive material, such as one or more of copper, silver, bronze, gold, brass, and the like, or semiconducting material. The voltage at a contact position on the resistive element **120** is applied to the brush **140** as the brush **140** moves across the resistive element **120**. This brush voltage, V_B, is provided to a position detector **145** which comprises circuitry capable of receiving the brush voltage, V_B, and generating an output signal indicative of the relative positions of the first and second surfaces **105, 110**.

Figure 2 shows a longitudinal cross-section through a position sensor **100** including a version of the resistive element **120'** which comprises a resistive strip **125** having a plurality of electrical leads **150, 155, 160**. By lead it is meant any electrical conductor connected to the resistive element or any site on the resistive element adapted to be contacted by an electrical conductor. In the version shown, end leads **150, 160** are located at or near the respective ends of a resistive strip **125**, or at or near ends of a section or portion of a resistive strip **125**. The end leads **150, 160** supply the resistive strip **125** with a first voltage. One or more intermediate leads **155** supply the resistive strip **125** with a second voltage. For example, the end leads **150, 160** may connect the ends of the resistive strip **125** to ground with the ends of the resistive strip **125** having a voltage substantially equal to zero. The intermediate lead **155** may be connected to the voltage source **130** and thereby apply a voltage to the resistive strip substantially equal to the voltage, V_S, from the voltage source **130**. The brush **140** of the contact element **135** contacts the resistive element **120** at a position along its length, for example at position x shown in Figure 2, so that a voltage may be applied from the resistive element **120'** to the brush **140**. This brush voltage, V_B, varies according to the position of the brush **140** along the resistive element **120'**, as shown in the Figure 2A. As can be seen, when the brush is located at the position of a first end lead **150**, the voltage applied to the brush **140** is substantially the voltage applied to the first end lead **150**, which in the version of Figure 2A is substantially zero. As the brush moves along the resistive strip **125**, the voltage increases until the brush is located at a position where the voltage from the voltage source **130** is supplied. The voltage then decreases as the brush **140** continues toward the position of the second end lead **160** and where the resistive strip **125** is again grounded.

The position detector **145** monitors the brush voltage, V_B, to determine the position of the second surface **110** relative to the first surface **105**. For example, when the brush **140** is at position x, a voltage v will be applied to the brush **140**, as shown in Figure 2A. The position detector **145** receives the signal indicating that the brush voltage, V_B, equals v and determines that the second surface is at position x. As can be seen from Figure 2A, the brush voltage, V_B, is equal to v at two locations, x and x'. The position detector **145** comprises circuitry and/or logic that allows the position to be unambiguously determined. For example, in one version, the position determination is performed incrementally where a change in brush voltage, V_B, represents a change in position. This is illustrated in Figure 2A, where a previous position, x_0, is registered in the position detector **145**. The next measured brush voltage, V_B, is determined to be v. The difference between the voltages ($v-v_0$) is used to determine the change

in position, and the position is determined to be the nearest position associated with that change of brush voltage. Accordingly, x is determined to be the position instead of x'. Since the time between movement from x_0 to x is known, the velocity of the surface movement can also be determined. This method of position and/or velocity detection is particularly useful when the sampling rate is sufficiently high, relative to the rate of movement of the second surface **110** with respect to the first surface **105**, to prevent inaccurate position determinations and when the direction of movement is known. Alternatively or additionally, a supplemental position sensor may be provided to aid in the determination of the relative positions of the surfaces, as will be discussed.

The position sensor **100** of Figure 2 is advantageous over conventional position sensors. For example, the position sensor **100** comprising a resistive element **120'** having an intermediately applied voltage has a higher resolution than a potentiometer which is grounded at one end and has a voltage applied to its other end. In addition, the position sensor **100** can include additional voltage inputs to provide high resolution position sensing over a larger range of positions. For example, as shown in Figure 3, the position sensor **100** may comprise three or more grounded leads, such as the five grounded leads **150, 160, 170, 180, 190** shown, and two or more intermediate leads, such as the four intermediate leads **155, 165, 175, 185** shown, which are connected to the voltage source **130**. The brush voltage, V_B, as a function of position of the brush **140** on the resistive element **120'** is shown in Figure 3A. The position x can be determined when the brush voltage, V_B, is detected to be v. The ambiguity can be resolved by high sampling rate incremental position detection or with a supplemental position detector, as discussed above.

In another version, the position sensor **100** comprises a version of the resistive element **120"** comprising a plurality of resistive strips each with a plurality of leads, as shown in Figure 4. The resistive element **120"** of this version comprises a first resistive strip **126** and a second resistive strip **127** each including a first lead **200, 210** at first ends of respective resistive strips and a second lead **205, 215** at second ends of the resistive strips. The first leads **200, 210** supply a first voltage, such as by being connected to ground, and the second leads **205, 215** provide a second voltage, such as V_S from voltage source **130**. Between the resistive strips **126,127** is a non-conducting portion **220** that is less conductive than the resistive material **121**. Accordingly, the brush voltage V_B as a function of the position of the brush **140** is shown in Figure 4A. The ambiguity may be resolved as discussed above. The version of Figure 4 is

advantageous in that the distance between x and x' is substantially constant along the length of the resistive element **120"**, except within the region of the non-conducting portion **220**. Thus, the resolution for a particular rate of relative movement of the surfaces can be easily determined, and for relatively low rates of movement, the resolution is substantially limited only by the thickness of the non-conductive portion **220**.

The non-conducting portion **220** is sufficiently thick to substantially prevent the voltage applied to an end of a first resistive strip **126** from affecting the voltage applied to the second resistive strip **127**. The non-conducting portion **220** may be provided by providing a gap between resistive portions. In one version, the non-conducting portion **220** may comprises one or more insulating or dielectric materials, such as a rubber, a plastic, a glass, or wood. For example, the non-conducting portion **220** may comprises an insulating fluoropolymer, such as PTFE. The non-conducting portion **220** is sufficiently thin to provide an acceptable sensor resolution and sufficiently thick to prevent undesirable voltage from passing from one resistive portion to another. Thus, for highly insulating non-conductive portions, an acceptable thickness can be less than an acceptable thickness for a less insulating non-conductive portions. The acceptable thickness is dependent on selected materials and design requirements. It may also be advantageous to provide an insulating material at the non-conductive portion to reduce bumps and surface irregularities that could add wear on the brush and reduce the life of the brush.

The position sensors **110** of Figures 3 and 4 may also be used to determine an absolute position of the first surface **105** relative to the second surface **110**. For example, the position detector **145** may comprise a cycle counter to allow for the absolute position sensing. The cycle counter may be designed to recognize and count cycles through which the brush **140** has passed. The cycle counter may comprise a peak detector or may recognize other distinguishing features of a cycle. Thus, when it has been recognized that the brush **140** of Figure 3, for example, has passed into its third cycle, the position detector **145** would register the coarse position of the brush **140** to be between leads **170** and **180**. The brush voltage V_B would then be used to determine the precise position within the coarse position range. To allow for the cycle counter to be used to detect absolute position when the first surface **105** and second surface **110** are relatively movable in opposite directions, such as in the positive and negative x directions, supplemental information may be provided to the position detector **145** to allow for the cycle counting, as will be discussed.

The position sensor **100** may comprise additional features in order to improve the position sensing abilities of the sensor. For example, the second surface **110** may comprise two or more contact elements **135**, such as a first brush **141** and a second brush **142**, that are fixedly spaced relative to one another. The position detector **145** detects a first brush voltage, V_{B1}, and a second brush voltage, V_{B2}. The voltages from the first brush **141** and the second brush **142** may be used to determine absolute position of the surfaces, to improve resolution, and/or to provide quadrature or the like to the position sensing.

Figure 5 shows one version of a position sensor **100** comprising a plurality of brushes. In this version, two laterally spaced resistive elements **120** are provided. A first brush **141** contacts a first resistive element **120** and a second brush **142** contacts a second resistive element **120**. The voltage source **130** applies a voltage, V_S, to the first resistive elements **120** in a manner that allows for improved position sensing. In another version, separate voltage sources may be provided for each resistive element **120**.

In one version, the additional resistive element may be provided to allow for absolute position sensing, as shown for example in the embodiments of Figure 6 and 7. In the version shown in Figure 6, the position sensor **100** comprises a resistive element **120'** similar to the resistive element of Figure 3 and a resistive element **120'''** comprising a resistive strip **125** with a grounded lead **230** at one end and a V_S supplied lead **235** at its other end. Figure 6A shows the first brush voltage, V_{B1}, as a function of position, and the second brush voltage, V_{B2}, as a function of position. The first brush **141** contacts the resistive element **120'** and the second brush **142** contacts the resistive element **120'''** at positions corresponding to position x, providing a first brush voltage of v_1 and a second brush voltage of v_2. The resistive element **120'** which has more V_s supplying leads, has a higher resolution than the resistive element **120'''** having only one V_s supplying lead **235**. However, the resistive element **120'''** with fewer V_s supplying leads has less ambiguity in that there is a single position x associated with a detected second brush voltage V_{B2}. As a result, the second brush voltage V_{B2} may be used to provide the coarse position, and the first brush voltage V_{B1} may be used to determine the fine position. Thus, the V_{B2} signal may be used to resolve the ambiguity created by the V_{B1} signal, in that it is unclear if the detected voltage v_1 relates to a position x, x', x", etc. For example, in one version, the position detector **145** may select the position to be the x value corresponding to v_1 that is the closest to the x value determined from the V_{B2} signal. Together, the two detected signals may be used to determine a high resolution absolute position of the first and second

surfaces **105, 110**. Alternatively, the resistive element **120'''** may comprise more than one V_s supplying lead, but fewer than the number of V_s supplying leads than the other resistive element **120'**.

In the version of Figure 7, a coarse position determining resistive element **120'''** is used with a resistive element **120"** comprising a plurality of resistive strips **126, 127, 128, 129**, like the resistive element **120"** of Figure 4. First ends of the resistive strips **126, 127, 128, 129** comprise grounded leads **200, 210, 250, 260** and second ends comprise leads **205, 215, 255, 265** which are connected to the voltage source **130**. The coarse position determining resistive element **120'''** is similar to the resistive element **120'''** in the version of Figure 6. Thus, in the version of Figure 7, the second brush voltage V_{B2} is again used to determine a coarse position and the first brush voltage V_{B1} is used to finely resolve the position, as shown in Figure 7A.

The versions of Figures 6 and 7 may have resolution capabilities that vary across the sensor **100**. For example, the resolution of the version of Figure 6 is limited primarily to the resolution near the peaks **240** and valleys **245** of the V_{B1} signal, as shown in Figure 6A. At the peaks **240** and valleys **245**, the positions of x and x' become increasingly close. When the distance between x and x' is less than the resolution of the resistive element **120'''**, an ambiguity may exist over these peak and valley portions. In addition, the actual peak and/or valley may be rounded due to the thickness of the lead attachment in some instances. Thus, it may be difficult to determine if a measured voltage, v_1, should be associated with x or with x', and the sensor may have regions of high resolution and regions of less high resolution. In contrast, the distance from x to x' in the version of Figure 7 is substantially constant. Thus, if the resolution of the coarse position determining resistive element **120'''** is higher than the distance from x to x', the resolution of the position sensor **100** of the version of Figure 7 is limited primarily by the thickness of the non-conductive portion **220**. Since the portions where resolution is limited is known for each of the versions, supplemental position determination can be made at those versions. Alternatively, no supplemental determination may be provided and the overall resolution can be considered to be the resolution at these less resolute areas. Alternatively, the position detector **145** may use logic to determine when the determined position is known to be at a first resolution and when the determined position is known to be at a second resolution.

Figure 8 shows another version of a position sensor **100** of the type shown in Figure 5. In this version, the position sensor **100** comprises two resistive elements **120'** similar to the resistive element **120'** of Figures 2 and 3 where each resistive element **120'** comprises a resistive strip with three or more leads. One resistive element **120'** comprises leads **150, 160, 170, 180, 190** connected to ground and leads **155, 165, 175, 185** supplying a voltage V_s to the resistive strip **125**. The other resistive element **120'** comprises grounded leads **270, 280, 290, 300** offset from the grounded leads in the first resistive element **120'** and with voltage supplying leads **275, 285, 295, 305** offset from the voltage supplying leads in the first resistive element **120'**. For example, by shifting the leads of the resistive elements so that the respective V_{B1} and V_{B2} cycles are out of phase of one another, for example by being 90 degrees out of phase as shown in Figure 8A, quadrature can be provided. For every position in a cycle there is a unique combination of values of V_{B1} and V_{B2}. Accordingly, the direction of movement can be determined by the position detector **145**. In addition, resolution may be increased since a signal at a peak **240** or a valley **245** may be supplemented by the other signal, which is not at a peak **240** or valley **245** as can be seen from Figure 8A. In an advanced version, the position detector **145** may place more weight on the signal that is not at a peak **240** or valley **245** thereby further improving resolution.

Another version of the invention of Figure 5 is shown in Figure 9. In this version, the position sensor **100** comprises two resistive elements **120"** similar to the resistive element **120"** of Figure 4. Each resistive element **120"** comprises a plurality of resistive strips **126, 127, 128, 129** separated by non-conductive portions **220**. The resistive strips **126, 127, 128, 129** of the two resistive elements **120"** are offset relative to the first resistive strip **126** so that the non-conductive portions **220** do not overlap one another. The resulting voltage profile is shown in Figure 9A. This version has an improved resolution in that the effects of the non-conductive portion **220** can be compensated. For example, when the first brush voltage V_{B1} is detected to be at or near zero, the second brush voltage V_{B2} can be primarily used in making the position determination. Similarly, when the second brush voltage V_{B2} is at or near zero, the first brush voltage V_{B1} can be used. In this way, the signal that is primarily be used for making the determination is the signal that is in the linear section of its voltage profile and is thus the most accurate.

Figures 10, 11, and 12 show alternative versions of position sensors **100** comprising two resistive elements **120**. In the version of Figure 10, the position sensor **100**

comprises a resistive element **120'** like the one of Figures 2 and 3 where the resistive element **120'** comprises a resistive strip **125** having alternating grounded and voltage supplying leads. The position sensor also comprises a resistive element **120""** comprising a plurality of spaced resistive strips **125** each comprising a grounded lead **350, 360, 370, 380** and a voltage supplying lead **355, 365, 375, 385**. In one version, the length of the resistive strips **125** in the resistive element **120""** is about half the length of a cycle in the resistive element **120'**, as shown in Figure 10. The resulting first brush voltage and second brush voltage profiles are shown in Figure 10A. The position detector **145** may examine the second brush voltage V_{B2} to aid in the position determination. For example, a non-zero voltage on the second brush **142** may indicate to the position detector **145** that the detected first brush voltage V_{B1} corresponds to the positive slope portion of the cycle of the voltage profile, thereby reducing ambiguities. Additionally or alternatively, the second brush voltage V_{B2} could be used by a cycle counter to allow for an absolute position determination. In another version, the resistive strips **125** in the resistive element **120""** may be more numerous and more closely spaced to provide for encoder-like position detection. In another version, as shown in Figure 11, the position sensor **100** comprises two resistive elements **120""** like the second resistive element **120""** in Figure 10. Each resistive element **120""** comprises a series of longitudinally spaced resistive strips **125**. In the version shown, when one of the brush voltages is substantially zero, the other brush voltage is used for the position determination. The position sensor **100** in the version of Figure 12 comprises a resistive element **120"** like the resistive element **120"** in the version of Figure 4 and a resistive element **120'** like the resistive element **120'** in the version of Figures 2 and 3. The resulting voltage profiles, as shown in Figure 12A, may be used for increased resolution during position detection, for quadrature-type determinations, and/or for absolute position detection. Other hybrid variations of the above described sensor arrangements may also be used. In addition, three or more resistive strip versions with a corresponding number of contact elements may also be used.

In another version, supplemental position information can be obtained without having to provide a second resistive element **120**. For example, in the version of Figure 13, the contact element **135** comprises a first brush **143** and a second brush **144** longitudinally spaced from the first brush **143**. Each brush contacts, or otherwise engages, the resistive element **120**. Figures 14 and 15 show versions of the position sensor **100** comprising longitudinally spaced brushes. In Figure 14, the resistive element **120'** is like the resistive element **120'** in Figures 2 and 3. In Figure 15, the resistive element **120"** is like the resistive element **120"** in Figure 4. In

the versions shown, the second brush **144** contacts the resistive element **120', 120"** at a position producing a V_{B2} profile 90 degrees out of phase with the V_{B1} profile, as shown in Figures 14A and 15A. Accordingly, the V_{B1} and V_{B2} voltage profiles for the version of Figure 14 are substantially the same as the voltage profiles for the version of Figure 8, and the V_{B1} and V_{B2} voltage profiles for the version of Figure 15 are substantially the same as the voltage profiles for the version of Figure 9. Thus, the version of Figure 14 is particularly useful for resolving ambiguities and for making movement direction determinations, and the version of Figure 15 is particularly useful in making position determinations when one of the brushes is located at one of the non-conductive regions **220**. In addition, the versions of Figures 14 and 15 are advantageous in their reduced power requirements.

The position sensor **100** may also be used to detect the angular position of two relatively rotatable surfaces, such as a shaft that rotates relative to another surface. Each of the versions of the position sensor **100** discussed above may be modified to detect angular position. For example, the position sensor **100** of Figure 16 is rotationally analogous to the linear version of the position sensor shown in Figure 8. The version of Figure 16 comprises two resistive elements **120'** having different diameters. The outer resistive element **120'** comprises grounded leads **300, 310, 320, 330, 340, 350, 360, 370** and voltage supplying leads **305, 315, 325, 335, 345, 355, 365, 375** that alternative with the grounded leads, as shown in Figure 16. The inner resistive element **120'** comprises grounded leads **380, 390, 400, 410, 420, 430, 440, 450** and voltage supplying leads **385, 395, 405, 415, 425, 435, 445, 455**. The inner leads are offset from corresponding leads on the outer resistive element **120'** so as to produce a V_{B2} signal that is 90 degrees out of phase with the V_{B1} signal, as discussed above in connection with Figure 8. The physical offset angle depends on the number of leads provided. For example, in the version shown, eight voltage supplying leads and eight grounded leads are provided. Thus, a V_{B1} cycle occurs for every 45 degrees of rotation. Accordingly, the leads of the inner element are shifted about 11.25 degrees relative to the outer leads. As a result, the V_{B1} and V_{B2} profiles shown in Figure 18 may be produced. The same V_{B1} and V_{B2} profiles can be produced by using a single resistive element **120'** and having angularly offset brushes **143, 144**, as shown in Figure 17 which is a version analogous to the linear version of Figure 14. Since the version of Figure 17 also has eight grounded and eight voltage supplying leads, the brushes **143, 144** are also offset by about 11.25 degrees. Alternatively, the brushes **143, 144** may be offset by about 11.25 + n*45 degrees, where n equals an integer, to produce the voltage profile shown in Figure 18.

Offsets other than about 11.25 degrees, i.e. phase shifts of other than about 90 degrees, may alternatively be used.

Similarly, Figures 19 and 20 show angular rotation sensing versions of the linear position sensors shown in Figures 9 and 15, respectively. In the version of Figure 19, the position sensor **100** comprises an outer resistive element **120"** comprising a plurality of resistive strips **460-467** and an inner resistive element **120"** each comprising a plurality of resistive strips **470-477**. Each resistive strip has one end connected to ground and another end connected to a voltage source **130**. Adjacent resistive strips are separated by a non-conducting portion **220**. The inner strips are offset relative to the outer strips so that there is no overlap between non-conducting portions **220**. The resulting V_{B1} and V_{B2} profiles are shown in Figure 21. The same V_{B1} and V_{B2} profiles are obtainable from the version of Figure 20 where the inner resistive element **120"** is replaced by an offset first and second brush arrangement **143, 144**.

The position sensor **100** of the present invention is particularly advantageous for use with computer interface devices. Conventional low cost position sensors have less sensing accuracy than is desired for many interface application. For example, often interface devices require a very high sensing resolution to constantly update the velocity and/or position of a user manipulated object. For realistic and consistent forces to be output, a sensing resolution is needed that is greater than the typical mass-produced quadrature encoder can provide. However, to keep the costs of such interface devices viable for a consumer market, the position sensor must be relatively inexpensive. To provide the desired resolution, quadrature encoders having the desired increased resolution are typically too expensive to allow the computer interface device to be viably priced in the consumer market. Accordingly, in one version, the position sensor **100** of the present invention is used to detect user controlled position in an interface device.

Figure 22 is a schematic illustration of a user interactive system **500** according to the invention. A display **505** provides a graphical environment **510** to a user. Within the graphical environment **510** is a graphical image **515**. The graphical image **515** may be, for example, a cursor or other graphical object, the position, movement, and/or shape of which is controllable. For example, the graphical image **515** may be a pointer cursor, a character in a game, a surgical instrument, a view from the end of a surgical instrument, a representative portion of the user, or the like. Also within the graphical environment is a graphical object **120**

such as an icon, as shown, or any other graphical representation including another graphical image that may be controlled by the user or by another user. A controller **525** in communication with the display **505** is capable of generating and/or controlling the graphical environment **510**, for example by executing program code including an application program. A user object **530** is manipulatable by a user, and the manipulation of the user object **530** controls the position, orientation, shape and/or other characteristic of the graphical image **515** within the graphical environment **510**, for example by directly correlating a position of the user object **530** with a displayed position of the graphical image **515** or by correlating a position of the user object **530** with a rate of movement of the graphical image **515**. Either the entire user object **530** may be manipulatable by the user or a portion of the user object **530** may be manipulatable relative to another portion of the user object **530**. For example, the user object may be a surface that is engaged by one or more hands of a user, such as a joystick, a mouse, a mouse housing, a stylus, a knob, an elongated rigid or flexible member, an instrumented glove, or the like and may be moveable in from one to six degrees of freedom. The user object **130** includes a surface **105** that may be moved relative to another surface **110**. The relative movement is sensed by the position sensor **100** as discussed above.

Optionally, haptic feedback may be provided to the user to increase the realism of the interaction within the graphical environment **510**. For example, when a predetermined event occurs within the graphical environment **510**, such as an interaction of the graphical image **515** with the graphical object **520**, the controller **525** may cause an actuator **535** to output a haptic sensation to the user. In the version shown, the actuator **535** outputs the haptic sensation to the user object **530** through which the sensation is provided to the user. The actuator **535** and the user object **530** may be part of a haptic interface device **540**. The actuator **535** may be positioned in the haptic interface device **540** to apply a force to the user object **530** or to a portion of the user object. For example, the haptic interface device **540** may comprise a user object **530**, such as a mouse housing, having an actuator **535** within the user object **530**, such as a vibrating motor within the mouse housing, or the haptic interface device may comprise a user object **530**, such as a mouse, that is mechanically linked to an actuator **535**. Alternatively, the actuator **535** and the user object **530** may be separate structures, and the actuator **535** may provide a haptic sensation directly to the user, as shown by the phantom arrow in Figure 22.

The actuator **535** may provide the haptic sensation actively or passively. For example, the actuator **535** may comprise one or more motors coupled to the user object **530** to apply a force to the user or to the user object **530** in one or more degrees of freedom. Alternatively or additionally, the actuator **535** may comprise one or more braking mechanisms coupled to the user object to inhibit movement of the user or the user object **530** in one or more degrees of freedom. By haptic sensation it is meant any sensation provided to the user that is related to the user's sense of touch. For example, the haptic sensation may comprise kinesthetic force feedback and/or tactile feedback. By kinesthetic force feedback it is meant any active or passive force applied to the user to simulate a force that would be experienced in the graphical environment **510**, such as a grounded force applied to the user or the user object **530** to simulate a force experienced by at least a portion of the graphical image **515**. For example, if the graphical image **515** is positioned against a surface, a barrier or an obstruction, the actuator **535** may output a force against the user object **530** preventing or retarding movement of the user or the user object **530** in the direction of the barrier or obstruction. By tactile feedback it is meant any active or passive force applied to the user to provide the user with a tactile indication of a predetermined occurrence within the graphical environment **510**. For example, a vibration, click, pop, or the like may be output to the user when the graphical image **515** interacts with a graphical object **520**. Additionally, tactile feedback may comprise a tactile sensation applied to approximate or give the illusion of a kinesthetic force. For example, by varying the frequency and/or the amplitude of an applied vibration, variations in surface textures of different graphical objects can be simulated or by providing a series of clicks when a graphical image penetrates an object, resistance to the penetration can be simulated. For example, in one version a kinesthetic force sensation, such as a spring force, may be applied to the user whenever the graphical image **515** engages the graphical object **520** to simulate a selectively deformable surface. Alternatively or additionally, a tactile sensation, such as a pop, may be applied to the user when the graphical image **515** is moved across a surface of the graphical object **520** to simulate a texture of the graphical object **520**.

The controller **525** may be a computer, or the like. In one version, the controller **525** may comprise a processor and may be able to execute program code. For example, the controller **525** may be a personal computer or workstation, such as a PC compatible computer or Macintosh personal computer, or a Sun or Silicon Graphics workstation. The computer may be operable under the Windows™ , MacOS, Unix, or MS-DOS operating system or similar. Alternatively, the controller **525** can be one of a variety of home video game console systems

commonly connected to a television set or other display, such as systems available from Nintendo, Sega, Sony, and Microsoft. In other embodiments, the controller **525** can be a "set top box" which can be used, for example, to provide interactive television functions to users, or a "network-" or "internet-computer" which allows users to interact with a local or global network using standard connections and protocols such as used for the Internet and World Wide Web. The controller **525** may include a host microprocessor, random access memory (RAM), read only memory (ROM), input/output (I/O) circuitry, and/or other components of computers well-known to those skilled in the art. The controller **525** may implement an application program with which a user is interacting via peripherals, such as haptic interface device **540** and/or user object **530**. For example, the application program can be a simulation program, such as an interactive digital mockup of a designed feature, a medical procedure simulation program, a game, etc. Specifically, the application program may be a computer aided design or other graphic design program, an operating system, a video game, a word processor or spreadsheet, a Web page or browser that implements, for example, HTML or VRML instructions, a scientific analysis program, or other application program that may or may not utilize haptic feedback. Herein, operating systems such as Windows™, MS-DOS, MacOS, Linux, Be, etc. are also referred to as "application programs." The application program may comprise an interactive graphical environment, such as a graphical user interface (GUI) to allow the user to input information to the program. Typically, the application provides images to be displayed on a display screen and/or outputs other feedback, such as auditory signals. The controller **525** is capable of generating a graphical environment **510**, which can be a graphical user interface, game, simulation, such as those described above, or other visual environment. The controller **525** displays graphical objects **520**, such as graphical representations and graphical images, or "computer objects," which are not physical objects, but are logical software unit collections of data and/or procedures that may be displayed as images by the computer on display screen, as is well known to those skilled in the art. The application program checks for input signals received from the electronics and sensors of the user object **530**, and outputs force values and/or commands to be converted into haptic output for the actuator **535**. Suitable software drivers which interface such simulation software with computer input/output (I/O) devices are available from Immersion Corporation of San Jose, California. Display screen can be included in the computer and can be a standard display screen (LCD, CRT, flat panel, etc.), 3-D goggles, or any other visual output device.

The user interactive system **500** may be any one of a variety of systems. In one

version of the user interactive system **500**, the user object **530** comprises a goniometer **550** capable of sensing angular rotation of a joint on a body, as shown in Figure 23. For example the goniometer **550** may comprise a first surface fixed to a link on one side of the joint and a second surface fixed to a link on the other side of the joint. A position sensor **100** may be positioned to sense the relative movement of the surfaces and thereby detect the angular rotation of the joint. The goniometer may be used to diagnostically and/or anatomically study the movements of the joint. Alternatively or additionally, the movement of the joint may be used to interact with a simulation system, such as disclosed in U.S. Patent 6,110,130 which is incorporated herein by reference in its entirety. A signal indicative of the detected manipulation is provided to the computer **525**, via the position detector **145**, to control the position, orientation, and/or shape of the graphical image **115**, which may be for example a graphical hand **170**. As shown in Figure 23, an analog to digital converter **555** may converts the signal from the position detector **145** to a digital signal that may be provided to the computer **525** through bus **560**. In another version, the position sensor **100** may be used to detect the rotational position of a knob, such as a knob disclosed in U.S. Patent 5,889,672 which is incorporated herein by reference in its entirety. In other versions, the position sensor **100** may be used to detect manipulation of a mouse, such as the mouse disclosed in U.S. Patent 6,100,874 or in U.S. Patent 6,211,861, both of which are incorporated herein by reference in their entireties, or of a scroll wheel of a mouse. The sensed manipulation by the user may also or alternatively be used to the operation of physical devices, such as a slave device in robotics. For example, in one version, the position of a user's hand may be sensed by a position sensor **100** may be used to control an anthropomorphic robot hand or the like.

In other versions of the invention, the voltage supply configurations of the above-described embodiments may be varied. For example, instead of being grounded, the leads shown as being grounded may be connected to a voltage supply that provides a voltage different than V_s, such as negative V_s. Alternatively, different values of V_s may be provided for each cycle. Also, the voltage may be provided to the contact element **135** rather than to the resistive element **120**. For example, Figure 24 shows a version of a position sensor **100** similar to the version of Figure 2, but with the voltage supply being connected to the brush **140**. The resulting voltage profile of the version of Figure 24 is similar to that shown in Figure 2a. The voltage may be supplied to the contact element **135** in the other described versions as well. In another version, the voltage may be supplied to portions of the position sensor **100** in order to reduce the power consumption of the position sensor **100**. For example, in the version of Figure

25, a voltage controller such as a power commuting mechanism **600** may be provided to regulate the provision of the voltage from the voltage supply **130**. In the version shown the power commuting mechanism may comprise electrical switches or the like that provide the voltage, Vs, to the portion of the position sensor **100** where it is needed. The power commuting mechanism **600** may be under the control of the controller **525** or a separate controller, such as a local controller in the interface device. In one version, the power commuting mechanism **600** is adapted to provide substantially no power to at least one portion of the resistive element, for example, by not powering the portion of the resistive element **120** which is furthest from the contact element **135**. In a rotation version, the portion furthest from the contact element **135** may be considered to be the portion diametrically opposite to the portion being contacted by the contact element **135**. In another version, the power commuting mechanism **600** may be adapted to provide power substantially only to the portion of the resistive element **120** being contacted by the contact element **135** at a particular time, as shown in the version of Figure 25.

While this invention has been described in terms of several preferred embodiments, it is contemplated that alterations, permutations and equivalents thereof will become apparent to those skilled in the art upon a reading of the specification and study of the drawings. Also, more or less than eight, such as two or four, of each type of lead may be provided for the rotational embodiments. In addition, the resistive element **120** may be an arc less than an entire circle to sense a portion of an angular rotation. Furthermore, certain terminology, such as terms like x, y, z, left, right, up, down, etc., has been used for the purposes of descriptive clarity, and not to limit the present invention. Therefore, the appended claims should not be limited to the description of the preferred versions contained herein and should include all such alterations, permutations, and equivalents as fall within the true spirit and scope of the present invention.